Coal Thickness Gauging Using Elastic Waves

Soheil Nazarian
The University of Texas at El Paso
Center for Highway Materials Research
El Paso, TX 79968
(915) 747-6911

Yoseph Bar-Cohen
Jet Propulsion laboratory
NDE &Advanced Actuators
Pasadena, CA 91109-8099
(818) 354-2610

Abstract
The efforts of a mining crew can be optimized, if the thickness of the coal layers to be excavated is known before excavation. Wave propagation techniques can be used to estimate the thickness of the layer based on the contrast in the wave velocity between coal and rock beyond it. Another advantage of repeated wave measurement is that the state of the stress within the mine can be estimated. The state of the stress can be used in many safety-related decisions made during the operation of the mine. Given these two advantages, a study was carried out to determine the feasibility of the methodology. The results are presented herein.

Methodology

As indicated above, An important aspect of this project is to determine the thickness. If the wave velocity is known, the impact-echo method can be used to determine the thickness of the coal. The method is based on measuring the travel time of reflected waves from the bottom of a layer. Understanding that the reflected wave generates a standing wave within the layer, the response of a receiver is Fourier-transformed so that the frequency associated with the standing wave, f_r, can be determined. The thickness, T, can be found using

$$T = \frac{V_P}{2 f_r} \qquad (1)$$

where V_P is the compression wave velocity.

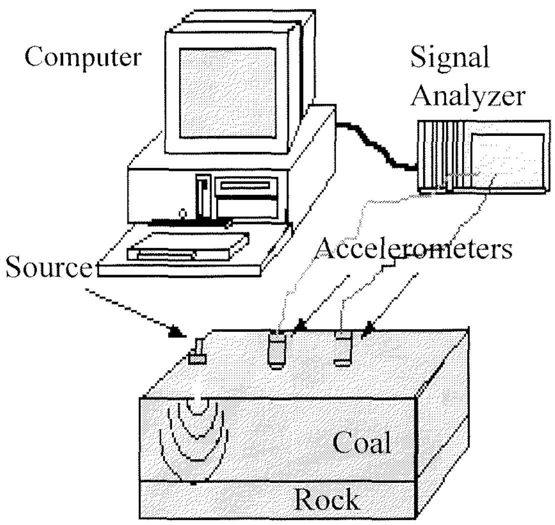

Figure 1 – Schematic Test Setup

The compression wave velocity needed for Equation 1 is nondestructively measured by using the high-frequency surface waves (a.k.a. ultrasonic surface waves, USW or SASW). Typically, a seismic source and at least two receivers are needed (see Figure 1). The surface of the medium is impacted and the transmitted waves are monitored with the receivers. By conducting a spectral analysis, a so-called dispersion curve (a plot of velocity of propagation of surface waves with wavelength such as the one shown in Figure 2) is obtained. The average modulus of the top layer, E_{USW}, can be simply obtained from the average phase velocity of the top layer, V_{ph}, from

$$E_{USW} = 2\rho(1+\nu)[(1.13 - 0.16\nu)V_{ph}]^2 \quad (2)$$

Baker et al. (1995) have developed a device that can perform these tests, in the field, in less than one minute per point.

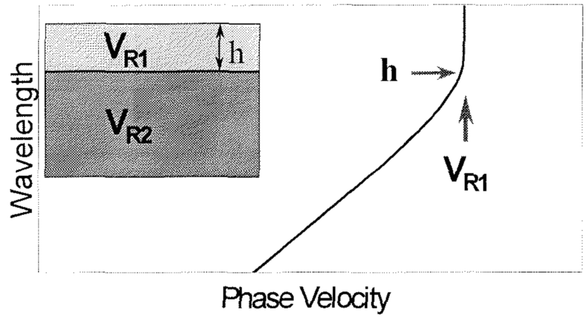

Figure 2 – Idealized Dispersion Curve

Typical Results

Typical time records from a numerical analysis are shown in Figure 3 for a case where the velocity of the propagation of rock is three times faster than the coal. The records correspond to equally spaced sensors placed about 0.5 times the thickness of the coal. Since the rock is stiffer than the coal seam, the refracted waves seem to be the first arrival. The automation of the refraction method has proven to be difficult because of heterogeneity of the coal and rock. Also from Figure 3, the surface wave energy is dominant in all records. The records shown here can be used to develop the dispersion curves. The dispersion curves from several normalized receiver spacings are shown in Figure 4. All of them follow one another closely. Each dispersion curve demonstrates a sharp change in the slope around a normalized wavelength of 1, indicating that the thickness can be determined. Also shown in Figure 4 is a theoretical dispersion curve determined from a simple one-dimensional model. The simplified dispersion curve follows the more complex ones reasonably well.

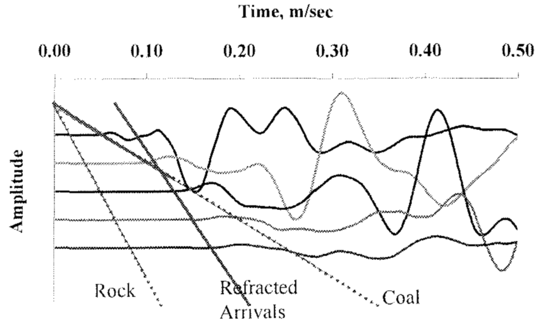

Figure 3 – Typical Time Records

The time records shown in Figure 3 can also be used to generate spectral functions needed for the Impact-Echo method. The results are shown in Figure 4 for three source-to-receiver spacings. Up to certain spacing, the frequency associated with the thickness resonance can be easily identified. When the source-to-receiver spacing becomes comparable to the thickness of the coal layer, the method does not yield satisfactory results.

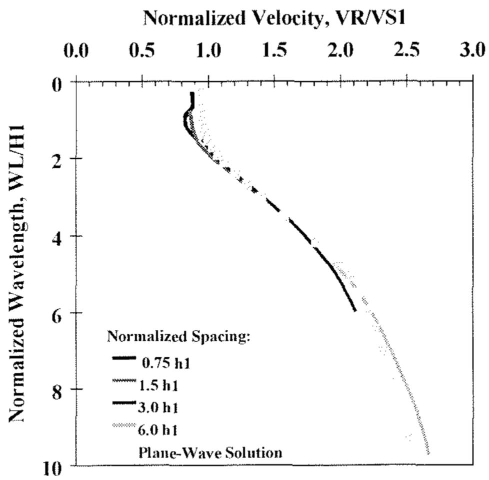

Figure 4 – Typical Dispersion Curves

Case Study

Finally to verify the results from the numerical study, several 1-m by 2-m models were constructed and tested. As an example, the dispersion curve measured from a 150-mm thick coalcrete (combination of coal, fly ash and concrete) over a layer of matured concrete is shown in Figure 5. The measured and numerically simulated results compare well. With both of them demonstrating a change in the slope at a wavelength very close to the actual thickness of the coal. Even though not shown, the impact-echo results were satisfactory as well.

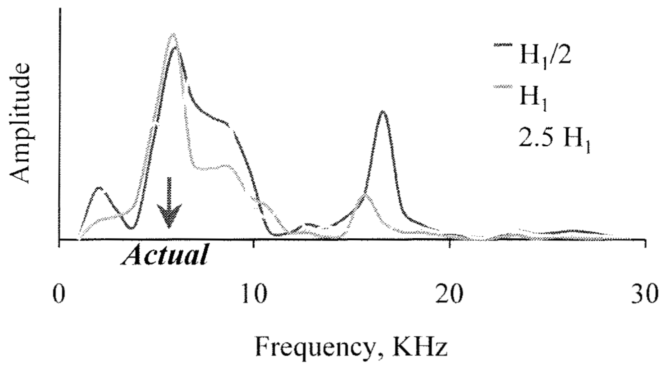

Figure 5 – Typical Impact Echo Results

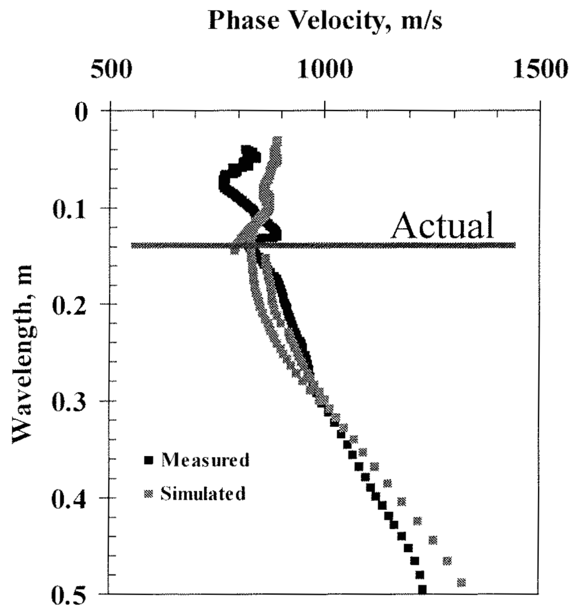

Figure 6 – Typical Experimental

Conclusion

This study demonstrated that the technology is quite feasible with good potential for automation. The thickness of the coal could be estimated with an accuracy of about 10% with an added benefit that the modulus of the coal can be measured and of the rock estimated.

Reference

Baker M. R., Crain K., and Nazarian S. (1995), "Determination of Pavement Thickness with a New Ultrasonic Device," Research Report 1966-1, Center for Highway Materials Research, The University of Texas at El Paso, El Paso, TX, 53 p.

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